Design of an Experiment for Evaluating the Impact of Visualization in a Bushfire Situation

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Abstract. This paper will explore and evaluate the practical implications of six chosen visualization techniques for communicating uncertainty and provide suitability measures and guidelines for the practical use. Additionally, it will detail a human subjects experiment design using these visualization techniques for evaluating decision-making in bushfire situations.

Keywords: uncertainty, geo-visualization, decision-making, bushfires.

1. Introduction

Making safety-critical decisions in potentially life-threatening hazardous situations is difficult, due to the time pressures involved with such a decision. Additionally, the uncertain nature of the relevant information available adds to the complexity. In Australia, there is a policy where it is the personal choice of the individual to vacate their home in the instance of a bushfire, rather than through the issuance of compulsory evacuation orders by the government. Thus, it is important to communicate predicted bushfire likelihood to a wide audience, from emergency response professionals to the general public, to aid in the decision of whether to stay or leave. This work is concerned with applying several different visualization techniques and evaluating them for decision-making in a bushfire setting. To achieve this, we utilize PHOENIX Rapidfire Bushfire Modelling software (which

predicts fire spread and outputs burn likelihood prediction areas) and examine different visualization techniques and their suitability for representing the uncertainty associated with this data. This research relies on a methodology for an objective human subjects experiment, presenting novice users with different scenarios and focusing on the decisions made from these different visualizations.

Whilst there is past experimental research into the effects of uncertainty visualization for decision-making in the context of natural hazards, these efforts have largely concentrated on experts and novices in situations such as avalanches (Kunz, Grêt-Regamey, & Hurni, 2011), tsunamis, floods (Trau & Hurni, 2007), seismic hazards and hurricanes (Pang, 2008). Past experimental research has not focused on testing the effects of uncertainty visualization from a bushfire decision-making situation. This research evaluates six carefully selected visualization techniques with human subjects in a bushfire context. The scenario used for testing these visualization techniques is one that is commonly encountered in bushfire situations – whether the information that you have been presented with influences a decision of whether you "stay" or "leave" your place of residence. Thus, we will present users with scenarios where their house is marked on the display; together with the burn likelihood represented using one of the above techniques.

The work presented here aims to provide answers to the challenges and questions outlined above and detail the process taken to solve these challenges. It outlines the decisions and rationale for static technique selection, the use of the underlying PHOENIX Rapidfire model *(Figure 1.1a)* to create the burn probability surfaces and lastly outlines some of the problems and choices made when designing the experiment interface. ESRI ArcGIS software *(Figure 1.1f)*, the Processing software package *(Figure 1.1h)*, PHP *(Figure 1.2c)*, Structured Query Language (SQL) *(Figure 1.2d)* and JavaScript *(Figure 1.2b)* were the technologies chosen for the implementation of this experiment.

This paper outlines the journey taken to design this experiment, from the selection of the representation techniques through to the design of the scenarios and experiment interface itself. For a start, visualizations have to be carefully considered for their inclusion both from a suitability perspective as well as having past experience of success, as supported by literature. After the selection process is complete, the experimental design process begins. There are many important choices to be made, what technology do we choose to build the experiment and how can we maximize our success through the experiment design and the interface itself?

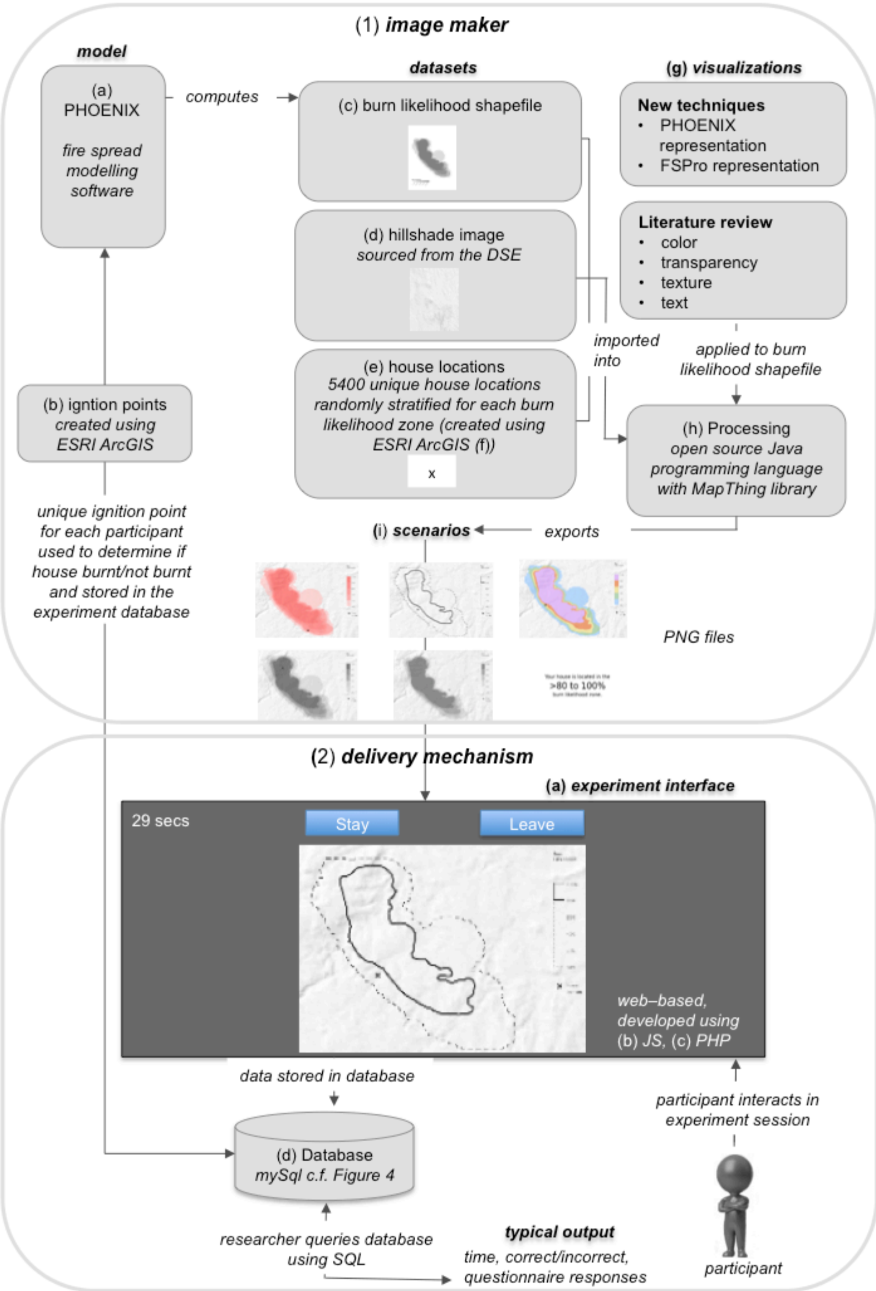

Figure 1. Schematic demonstrating interconnectedness of all the elements and processes used to design and create the experiment interface. At a broad level there are two main elements of the design, the *image maker* (1) and *delivery mechanism* (2). The image maker (1) creates the scenarios that are delivered to the participant through the delivery mechanism (2) of which the main feature is the experiment interface (2a) linked to a supporting database (2d).

The primary focus/aim of this research is to develop an experiment that is: intuitive, reusable, modifiable, robust, stand alone, with clean and uncluttered visualizations and interface.

2. Choosing visualizations

In choosing which visualization techniques to be included in the experiment we needed to achieve a fine balance between scenarios that have had past experience of success with those that had not been empirically tested before, but had potential for success. Based on a literature review, six static techniques were selected for their inclusion in the experiment – color *(Figure 2a)*, the PHOENIX representation *(Figure 2f)*, FSPro representation *(Figure 2b)*, transparency *(Figure 2c)*, texture *(Figure 2e)* and a textual description *(Figure 2d)*. These will soon be explained in further detail.

PHOENIX *(Figure 2f)* and FSPro *(Figure 2b)* were chosen as these representations are currently in use in the fire services sector today. These representations to our knowledge have not been previously tested for their suitability. The former is the visualization used to represent the current output from the PHOENIX model[1], which is represented as a hard line showing the highest burn likelihood, followed by a dashed line for the lowest burn likelihood. The latter is the representation used by the FSPro Prediction Model[2] which consists of bands of color to represent burn likelihood, with no clear value message. In addition, we chose three additional visualization techniques that are commonly used for communicating uncertainty, and are reported to be suited to representing quantitative categorical information (Bisantz et al., 2011; Bisantz et al., 2009; Leitner & Buttenfield, 2000). These techniques – transparency *(Figure 2c)*, texture *(Figure 2e)* and color value *(Figure 2a)* – have not been previously evaluated for decision-making in bushfire situations. Color was chosen (with a scale of richer to weaker to represent decreasing uncertainty) because it is a variation to the FSPro scenario but with the addition of containing a clear value message. Leitner and Buttenfield (2000) found it to be successful for depicting uncertainty in a regional planning scenario and best results were observed where a richer color was used to represent more certain information and a weaker color

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[1] Currently used by the Department of Sustainability and Environment and the Country Fire Authority in Victoria, Australia (http://www.bushfirecrc.com/news/news-item/mapping-ushfire-otential)

[2] Developed and used by the United States Department of Agriculture Forest Service in their Fire Decision Support Systems (http://wfdss.usgs.gov/wfdss_help/WFDSSHelp_FSPro_Ref.html)

used to represent less certain information. Transparency was chosen as it proved successful for representing uncertainty in an experiment Bisantz et al. conducted using a military decision-making task in 2011. This work was the extension of a previous study on transparency using human subjects conducted by Bisantz et al. (2009) which found it to be suitable for ranking levels of uncertainty in thunderstorm mapping.

Texture was described by Leitner and Buttenfield (2000) in their regional planning study, to be the next most successful following color saturation. Their representation of texture used finer texture to represent greater certainty.

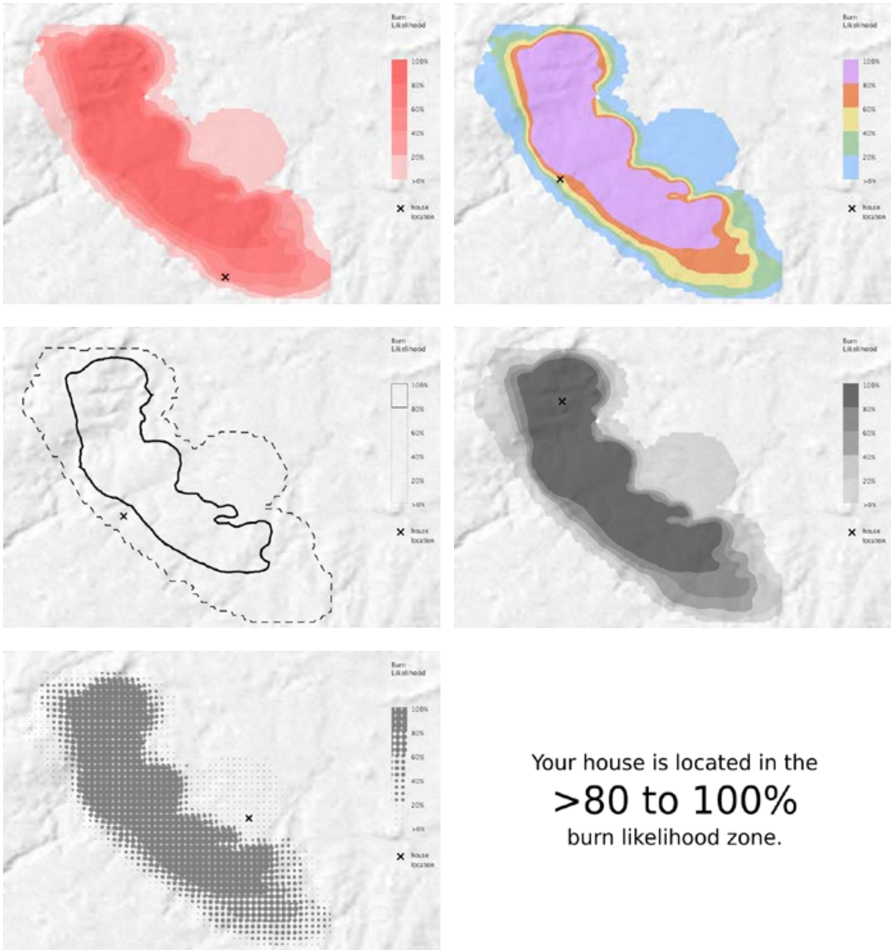

Figure 2. Example of uncertainty visualizations chosen and their depiction in the experiment (clockwise from top left) (a) color, (b) FSPro representation, (c) transparency, (d) textual representation, (e) texture and (f) PHOENIX representation.

To provide contrast, we also included a text-based representation of the predicted bushfire likelihood. This way we could evaluate whether representing uncertainty through visualizations is actually more effective for decision-making than simple text based descriptions.

3. Creating scenarios

Having selected our candidates for inclusion in the experiment, we come to the process of creating the scenarios that optimally display these candidates so they can be tested. Additionally, there were decisions to be made around which software we used in this development process. PHOENIX Rapidfire is fire spread modelling software developed by Kevin Tolhurst and Derek Chong at the University of Melbourne. Currently, it is used by the Department of Sustainability and Country Fire Authority to generate fire spread prediction in an Australian landscape and is built as an interface which interacts with ESRI ArcGIS. Its inputs include weather, topography, fuel loads, fire history, roads and suppression (Paterson & Chong, 2011). PHOENIX Rapidfire fit our software requirements perfectly, as it is reliably used by fire authorities in Victoria today and can be used to depict burn likelihood as a probability surface. We did not want to build our own model or tinker with existing less ideal models as the purpose of this work is not to create a model but rather to evaluate visualizations. We are trying to find the best method for representing the output of such models.

3.1. Generating a surface

The next step was to generate an uncertainty surface we could apply the above chosen visualization candidates to. In order to create a surface with PHOENIX, ignition points must be placed. We decided on 15 different scenarios so we could variably apply each of the candidates to these 15 scenarios. The choice of 15 was influenced by the decision that we wanted each participant to view roughly 100 scenarios, and 15 scenarios x 6 representations gives us 90 in total. We randomly placed 9 ignition points to generate each scenario. The 9 ignition points were created by placing a point in the centre of each grid cell of a randomly placed 3x3 grid. The random placement of this grid we restricted to a large area within the north-west of the study area. We did this to ensure the scenarios we generated did not fall outside the area of the map.

Next we used the Grid Analysis simulation type in PHOENIX to batch pro cess the scenarios with a 1m x 1m resolution and a 24-hour prediction window. The underlying weather conditions used for generation of the images

was taken from an area in Victoria that was particularly adversely affected by the Black Saturday bushfires of February 2009.

3.2. Assigning burn likelihood

Now we have a surface, but how do we assign values to create a probability surface? PHOENIX generates as part of its output a 'times impacted' column, indicating the number of times a particular grid cell has been impacted by both fire and embers. The distribution of these was firstly examined and then probabilities assigned (Table 1). Percentages were chosen as the method of communication, as the literature in this field indicates that percentages are most commonly used to represent probability for visualizations (Bisantz, et al., 2011) .

3.3. Creating the final image

To create the overall image that is viewed by the participants in the experiment, unique house locations *(Figure 1.1e)* were used and the true ignition point *(Figure 1.1b)* was randomly selected from the nine used to create the scenarios. The houses were placed as a randomly stratified sample, however we evenly distributed the houses throughout each of the probability zones. The true ignition point we used to define the actual area burnt. When a participant chooses to stay or leave, this true ignition point is used to determine whether they have made a right or wrong choice.

Together with the house location *(Figure 1.1e)* and the surface *(Figure 1.1c)*, the overall image included a hillshade image *(Figure 1.1d)* provided by the Department of Sustainability and Environment as a backdrop. We chose to use solely a hillshade image because we didn't want prior knowledge of the area to influence decision-making or proximity of the houses to roads to affect the choices made in the experiment. However, we still wanted a backdrop that represented real world features.

Times Impacted	Burn Likelihood (%)
8-9	>80-100
6-7	>60-80
4-5	>40-60
2-3	>20-40
1	>0-20

Table 1. Burn likelihood assigned to the surface according to the times impacted column in the output from PHOENIX, which is the number of times a particular grid cell has been impacted by fire or embers.

4. Designing an experiment interface

“Design is really an act of communication, which means having a deep understanding of the person with whom the designer is communicating” (Norman, 1990). The interface is the vehicle that delivers the scenarios that are viewed in the experiment and the only opportunity for the experimenters to communicate with the experimentees. This experiment is aimed at novices and hence it was designed that way. Regardless of all of the choices that were made previously, successful delivery of the experiment is not possible without a well-designed and executed experiment interface.

In designing our experiment interface, we reflect back on the overarching aims of this research – to design an experiment with an easy intuitive interface that doesn't require significant additional instruction and that would stand on its own. We wanted the display to be clear, uncluttered and as basic as possible so the visualizations themselves could shine through. The experiment system should be easily modifiable so it can be reused for future experiments of this nature. Another important requirement was a program to create the images themselves, as to create these manually would be an arduous process.

To best achieve our goals, it was decided that two separate interfaces should be built. One for automatic generation of the visulizations from the separate shapefiles and hillshade image i.e. *the image maker (Figure 1.1)*, and another for displaying to the subjects i.e. *the delivery mechanism (Figure 1.2)*. From the above requirements the experiment had to stand alone, so it could be run from any computer with a standard operating system and internet browser, it was clear that we needed a web interface and a database. PHP *(Figure 1.2c)* and JavaScript *(Figure1.2b)* were chosen to build the web interface, a MySQL database *(Figure 1.2d)* was chosen for data storage. These were chosen for simplicity because the designers had prior knowledge and experience with these languages. Processing *(Figure 1.1h)* was chosen to create the images as the authors have a strong desire for using open source software in keeping with sharing principles. Additionally, Processing handles the shapefiles created by the PHOENIX package well without any need for further manipulation or tinkering.

4.1. The image maker

Having chosen the Processing open source software package to create our images, we also discovered we needed to use an additional library – MapThing. The MapThing processing library was developed by Jon Reades at University College London’s Centre for Advanced Spatial Analysis

(Reades, 2012). MapThing cleverly enables Processing to read in and handle ESRI compliant shapefiles and display them as part of a sketch. The visual display of the shapefiles can then be programmatically manipulated using processing. Using the MapThing library and Processing, a java program was written to import and display the burn likelihood surfaces *(Figure 1.1.c)*, raster hillshade backdrop *(Figure 1.1d)* and 5400 unique house locations *(Figure1.1e)*. The program then automatically generates images based upon a combination of one of the 5 different visualizations *(Figure 1.1g)* and unique house locations overlaid on the hillshade background *(Figure 3)*. It also automatically generates the legend, shown to the right of the image, and matches the legend to the visualization of choice. These images are automatically batch saved as portable network graphic (PNG) images *(Figure 1.1i)*.

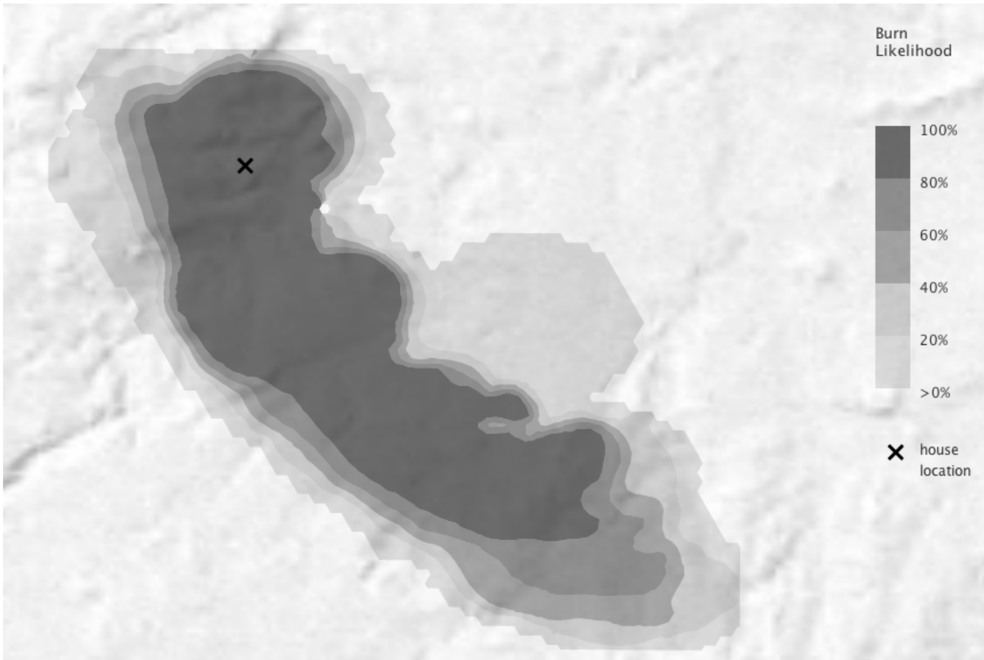

Figure 3. Example of the output generated from the Processing program.

4.2. The delivery mechanism

The next step in the experiment design is the creation of the delivery mechanism *(Figure 1.2)* encompassing the web interface *(Figure 1.2a)* and linked database *(Figure 1.2d)*.

In order to do this we needed first to take a brief look at the setup of our experiment. The experiment is a human subjects experiment for 60 participants where each participant views 90 scenarios. A ‘turn up’ fee is paid to participants for their participation in the experiment. They will be given 30 seconds to view each scenario and must make a decision of whether to stay or leave and press the corresponding button. The time limit of 30 seconds was chosen as we did not want to rush the participants into a decision but did want to impose reasonable time limit bounds around the experiment. The chosen time limit was based on initial pilot experiments; we initially started with 15 seconds but this was deemed by pilot participants to be too short. We also included a questionnaire at the end to facilitate further analysis of the decisions made. This questionnaire included some basic demographic questions about the participant as well as some questions to judge their maths ability, map reading ability and experience with bushfires.

Now reflecting back on the design process itself. We wanted the image containing the visualization *(Figure 3)* to have maximum screen real estate, so this was placed in the centre of the interface and was made as large as possible *(Figure 1.2a)*. As the experiments were timed, we obviously needed a timer. We decided on a count down timer, so participants could easily see how long they had remaining. In keeping with a clean interface, we placed it in the top left corner close to the image so it could be seen with a quick glance without the participant having to look away from the image. The stay and go buttons we placed at the top of the screen close to each other but not so close that the wrong button could be accidentally pressed *(Figure1.2a)*. We didn’t want people to have to move their mouse around too much. The design of the database was also based around simplicity and guided by the design of the experiment interface. We had a number of elements that needed to be stored; the ordering of the experiments for each individual, image names, burnt or not burnt information, time taken, response and all the information captured through the questionnaire.

All of this led to a database build that consisted of three tables: *experiment data*, *user data* and *questionnaire (Figure 4)*. The experiment data table stores information about the ordering of the experiment, including unique experiment numbers, image names and burnt and not burnt information. The user data table stores information about the actions of each user throughout the experiment including time taken, response and whether the response was correct or incorrect. The questionnaire table stores basic demographic information about the user as well as some basic questions about the experiment. All the images are stored as PNG images in the database and the ordering is contained in the experiment table. A unique, non-consecutive six-digit experiment number was created as an identifier for

each participant so the anonymity of the participants is maintained at all times.

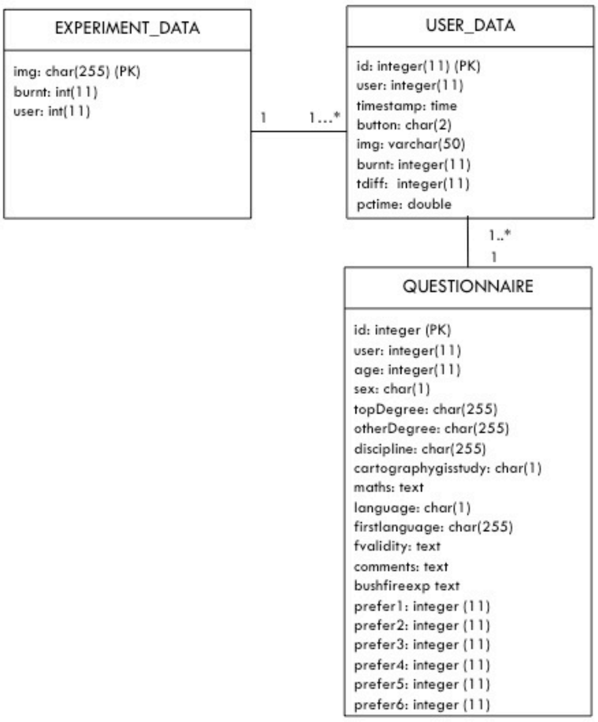

Figure 4. Database schema showing tables created for the experiment database.

In keeping with an experiment design that is fully stand-alone, the experiment was administered using a URL that the participants entered into a web browser. The six-digit number was entered into the experiment screen and this loaded the instructions and the experiment. Responses made by each participant were recorded in the user data and questionnaire tables corresponding to the unique participant number.

5. Conclusion

In conclusion, this paper outlines the journey we took for designing an experiment for evaluating uncertainty for decision-making in a bushfire situation. Our journey begins at the selection of visualizations then we travel

through to the creation of scenarios and culminates at the design of the experimental interface.

We now address each of the main aims we had for the interface in turn and outline how these have been met through the design process. The portability of the interface was adhered to as we created a web-based interface administered through a URL that works with all firefox browsers. The instructions for the experiment are in-built with the URL and the responses are recorded in a MySQL database. Initial pilot sessions using these experiments have proven successful and participants have commented through the questionnaire that the experiment interface was intuitive and easy to use with one participant commenting "very simple interface, clear instructions". The experiment is built with reusability in mind as the images and ordering are stored as separate components within the database. Therefore, if we wanted to use a different set of images or change/adjust the ordering, it would be a simple process of loading fresh images into the database *(Figure 1.1i)* and/or making changes to the experiment data database table *(Figure 1.1d)*. Furthermore, as each of the components of the experiment design are distinct from each other, it would be easy to reuse this experiment for a different hazard application area (e.g. by substituting a flood model in place of PHOENIX *(Figure 1.1a)*).

Initial pilot sessions using these experiments have proved successful.

6. Acknowledgements

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